# United States Patent [19]

**Bayh, III**

[11] **Patent Number: 4,625,798**

[45] **Date of Patent: * Dec. 2, 1986**


[54] **SUBMERSIBLE PUMP INSTALLATION, METHODS AND SAFETY SYSTEM**


[75] Inventor: **Russell I. Bayh, III**, Carrollton, Tex.

[73] Assignee: **Otis Engineering Corporation**, Dallas, Tex.



[*] Notice: The portion of the term of this patent subsequent to Jan. 17, 2001 has been disclaimed.

[21] Appl. No.: **697,051**

[22] Filed: **Jan. 31, 1985**

**Related U.S. Application Data**

[63] Continuation-in-part of Ser. No. 470,581, Feb. 28, 1983, Pat. No. 4,529,035.

[51] **Int. Cl.⁴** ........................ **E21B 43/00**; E21B 34/06

[52] **U.S. Cl.** ........................................ **166/106**; 166/319

[58] **Field of Search** ................ 166/105, 106, 319–324, 166/72; 417/190, 191



[56] **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 3,853,430 | 12/1974 | O'Rourke . | |
| 4,121,659 | 10/1978 | Taylor . | |
| 4,128,127 | 12/1978 | Taylor . | |
| 4,134,454 | 1/1979 | Taylor . | |
| 4,390,061 | 6/1983 | Short . | |
| 4,425,965 | 1/1984 | Bayh, III et al. . | |
| 4,440,221 | 4/1984 | Taylor et al. . | |
| 4,441,861 | 4/1984 | Canalizo . | |
| 4,474,234 | 10/1984 | Lefebvre et al. | 166/106 |
| 4,502,536 | 3/1985 | Setterberg, Jr. | 166/106 |
| 4,518,036 | 5/1985 | Lefebvre et al. | 166/106 |
| 4,529,035 | 7/1985 | Bayh, III | 166/106 |

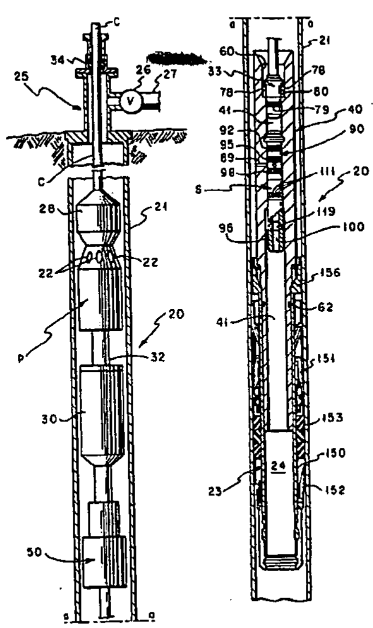


*Primary Examiner*—Stephen J. Novosad
*Assistant Examiner*—Bruce M. Kisliuk
*Attorney, Agent, or Firm*—Thomas R. Felger


[57] **ABSTRACT**


A landing nipple and safety system for installation in wells having a submersible pump for pumping formation fluids to the well surface plus a subsurface safety valve for maintaining the well under control during installation and removal of the pump from the well. The subsurface safety valve may be hydraulically actuated by either the discharge pressure of the pump or input power fluid for hydraulically powered pumps. The landing nipple to which the pump is attached and in which the safety valve is installed can be retrieved from the flow conductor by conventional wireline techniques.


**7 Claims, 31 Drawing Figures**



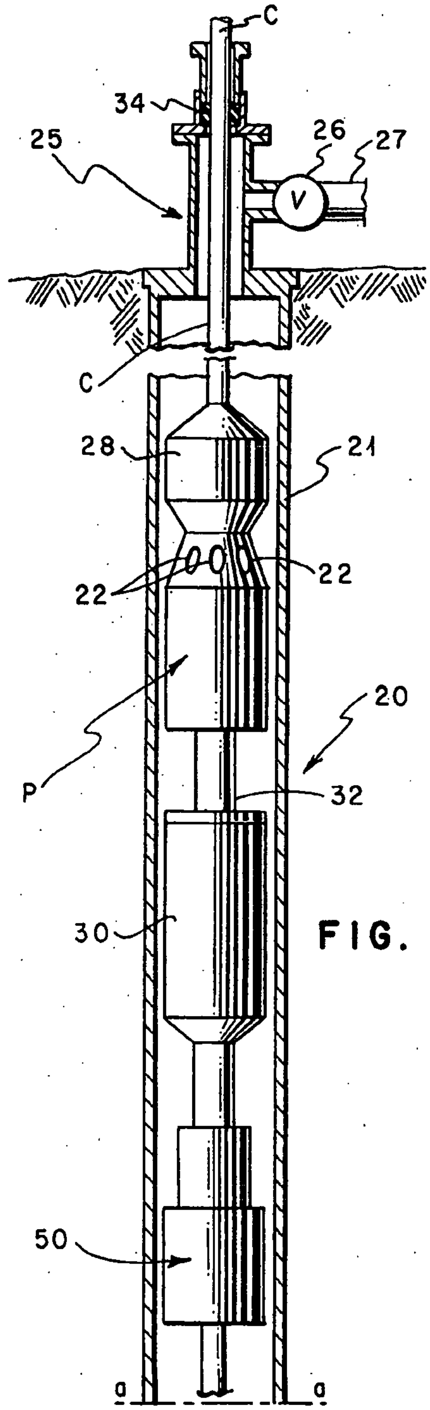

C
34
25
26
27
V
C
28
21
22
22
20
P
32
30
50
a
a

FIG. 1A

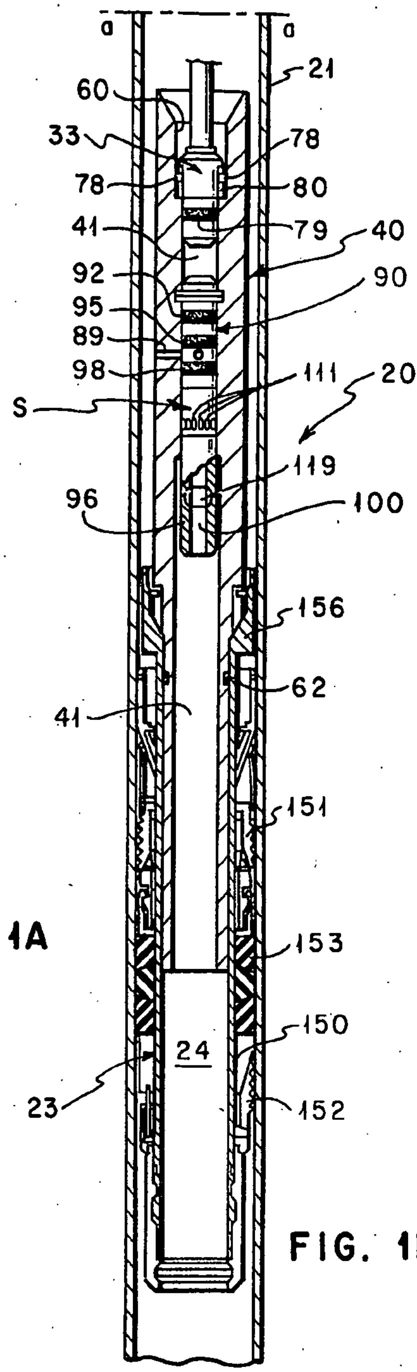

a
a
21
60
33
78
78
80
41
79
40
92
90
95
89
98
111
20
S
119
96
100
156
62
41
151
153
150
24
23
152

FIG. 1B

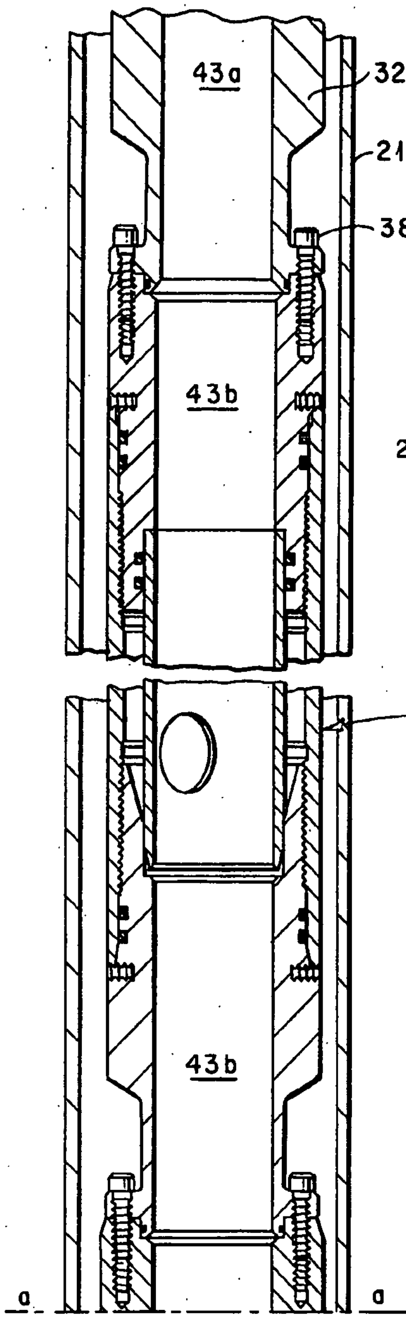

43a
32
21
38
43b
30
43b
a
a

FIG. 2A

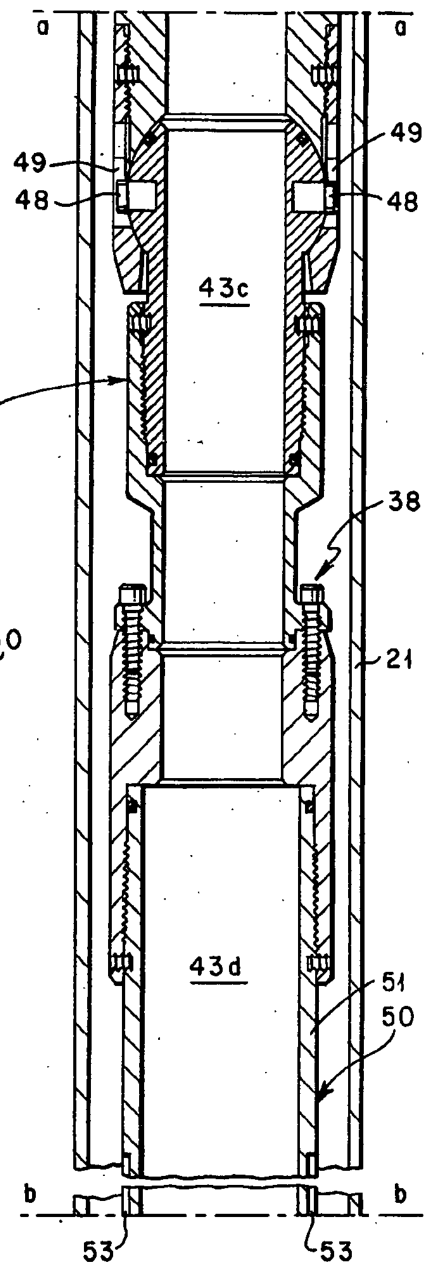

a
a
49
49
48
48
43c
29
38
21
43d
51
50
b
b
53
53

FIG. 2B

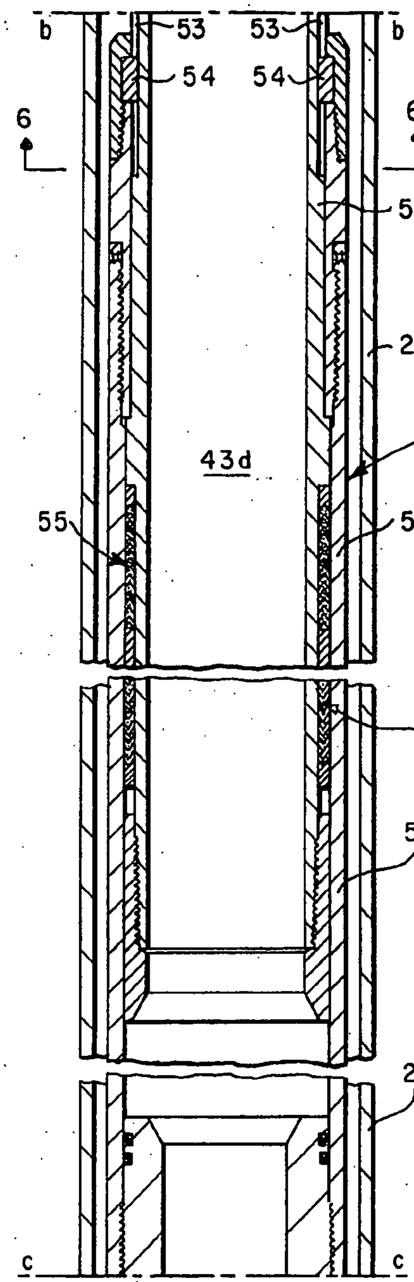

b
53
53
b
54
54
6
6
51
21
50
43d
55
52
55
52
21
c
c

FIG. 2C

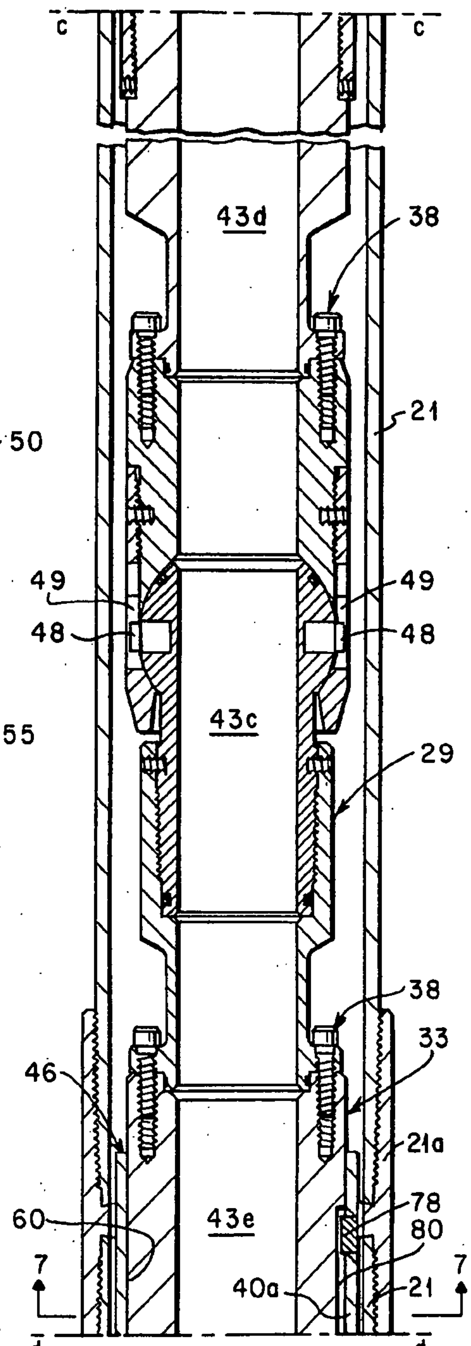
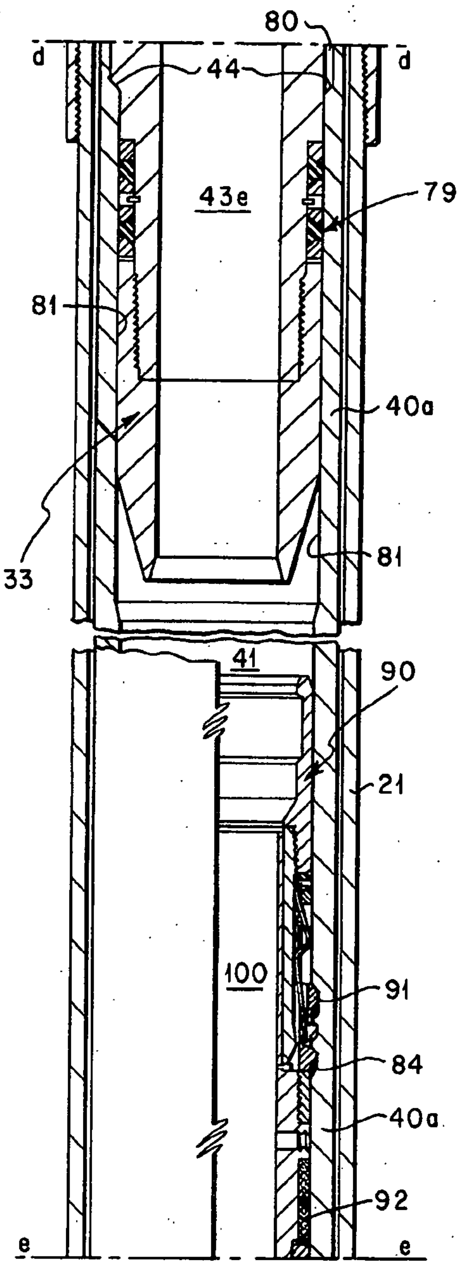
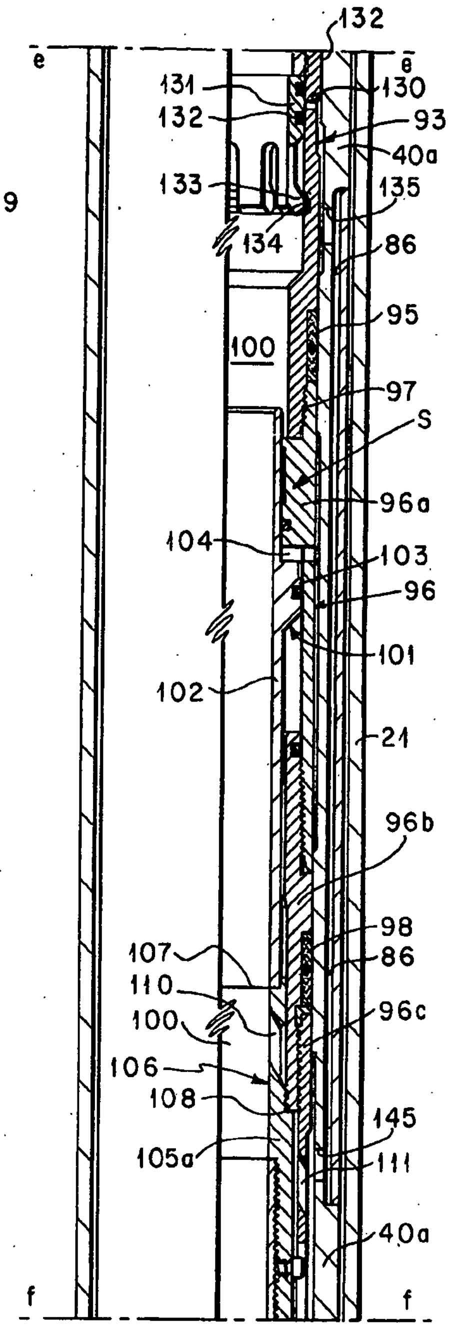

c
c
43d
38
21
49
49
48
48
43c
29
38
46
33
21a
43e
78
60
80
7
7
40a
21
d
d

FIG. 2D



d
80
d
44
43e
79
81
40a
33
81
41
90
21
100
91
84
40a
92
e
e


FIG. 2E



132
e
e
131
130
132
93
40a
133
135
134
86
95
100
97
S
96a
104
103
96
101
102
21
96b
98
107
86
110
96c
100
106
108
145
105a
111
40a
f
f


FIG. 2F

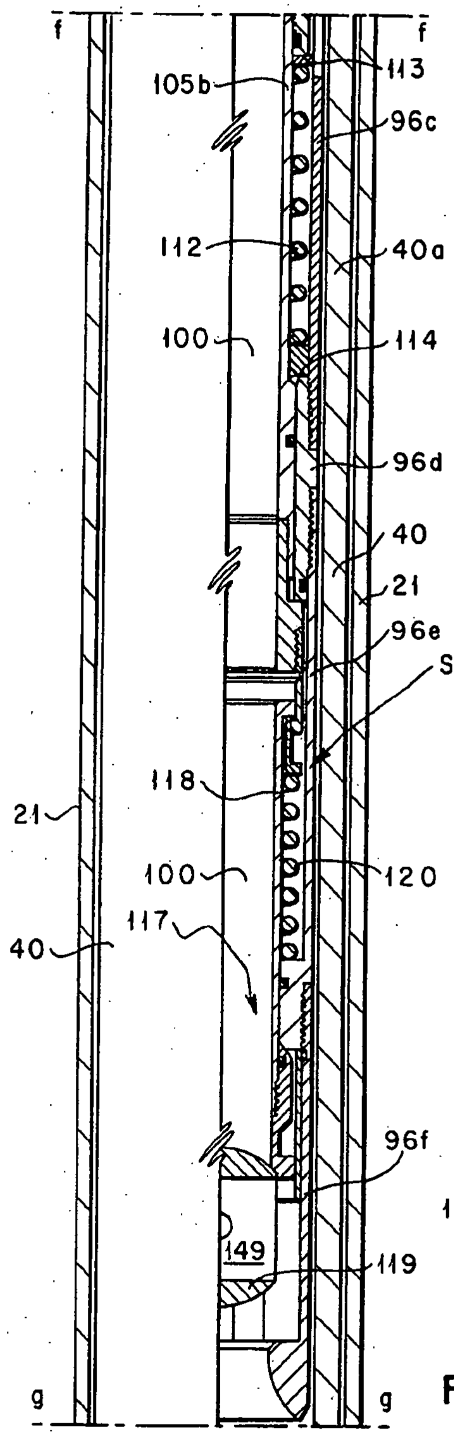

f
f
105b
113
96c
112
40a
100
114
96d
40
21
96e
S
118
21
100
120
117
40
96f
149
119
g
g

FIG. 2G

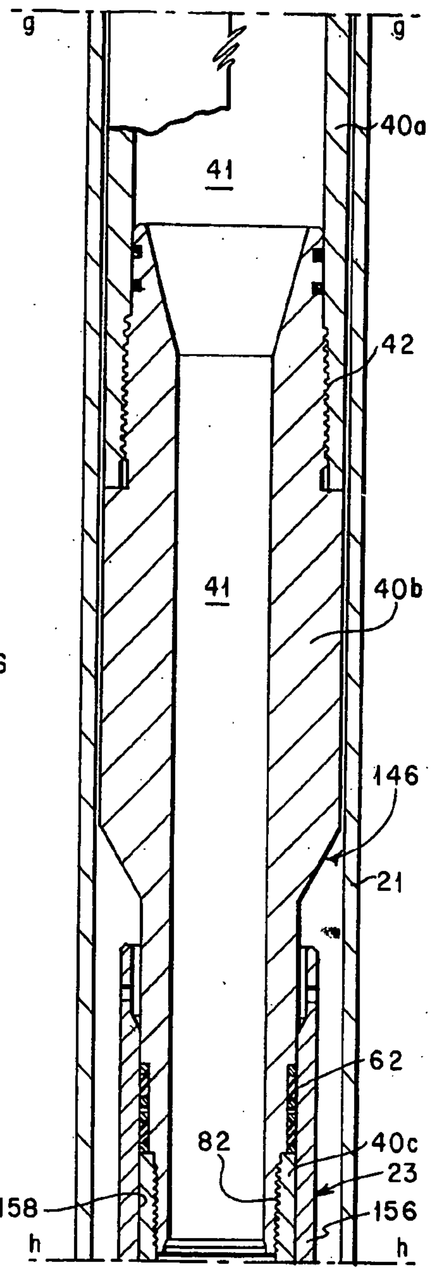

g
g
40a
41
42
41
40b
146
21
62
82
40c
23
158
156
h
h

FIG. 2H

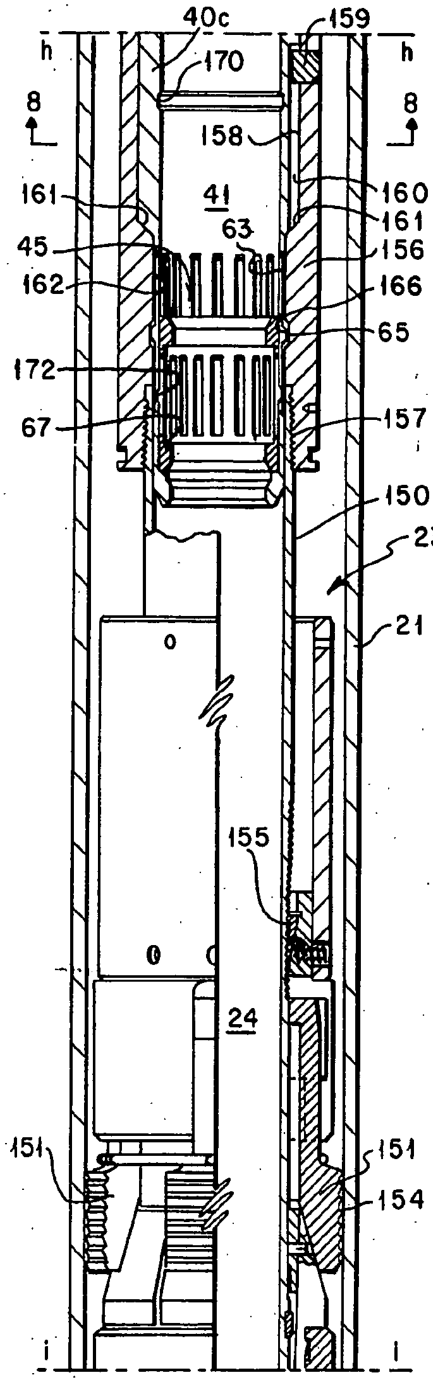

40c
159
h
170
h
8
8
158
41
160
161
161
63
45
156
162
166
65
172
157
67
150
23
21
155
24
151
151
154
i
i

FIG. 2I

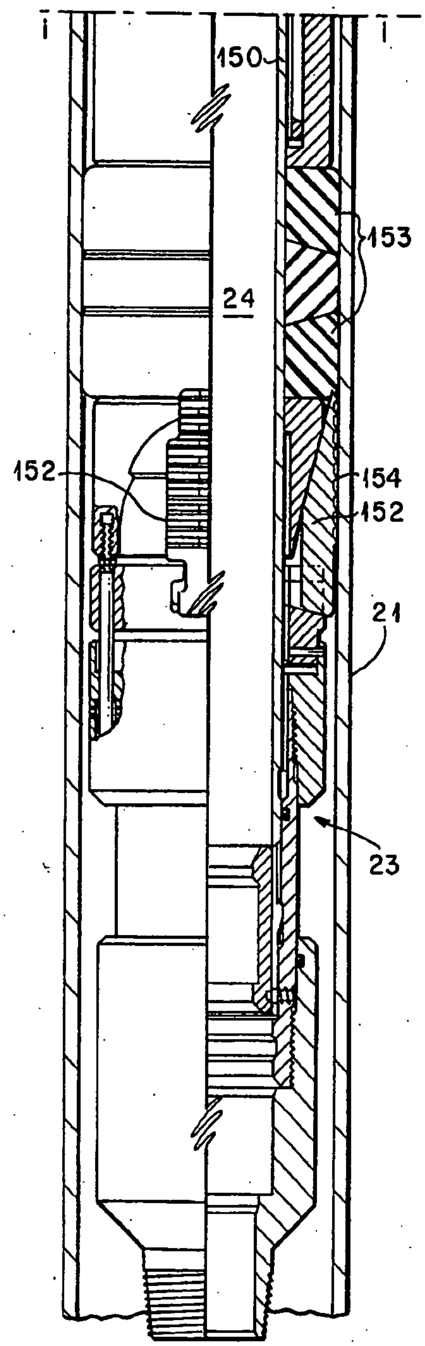

i
i
150
153
24
152
154
152
21
23

FIG. 2J

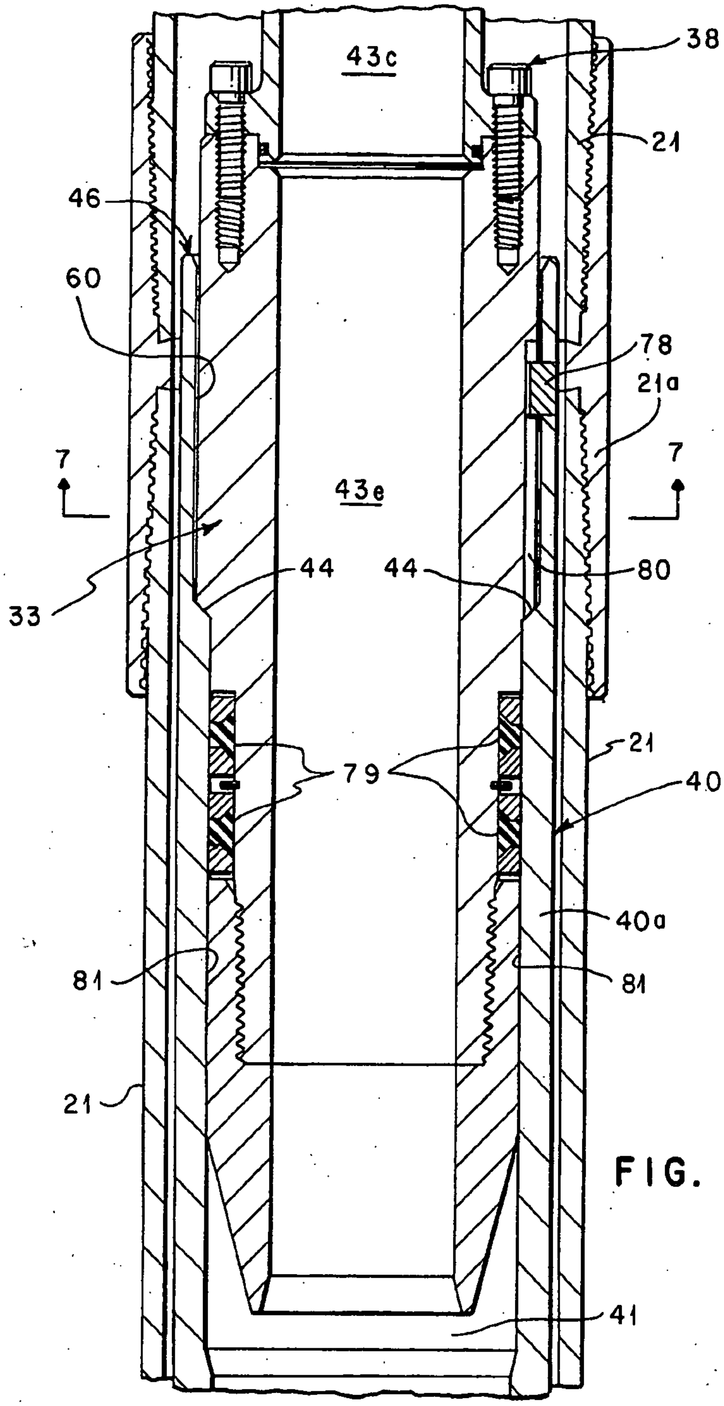



FIG. 3

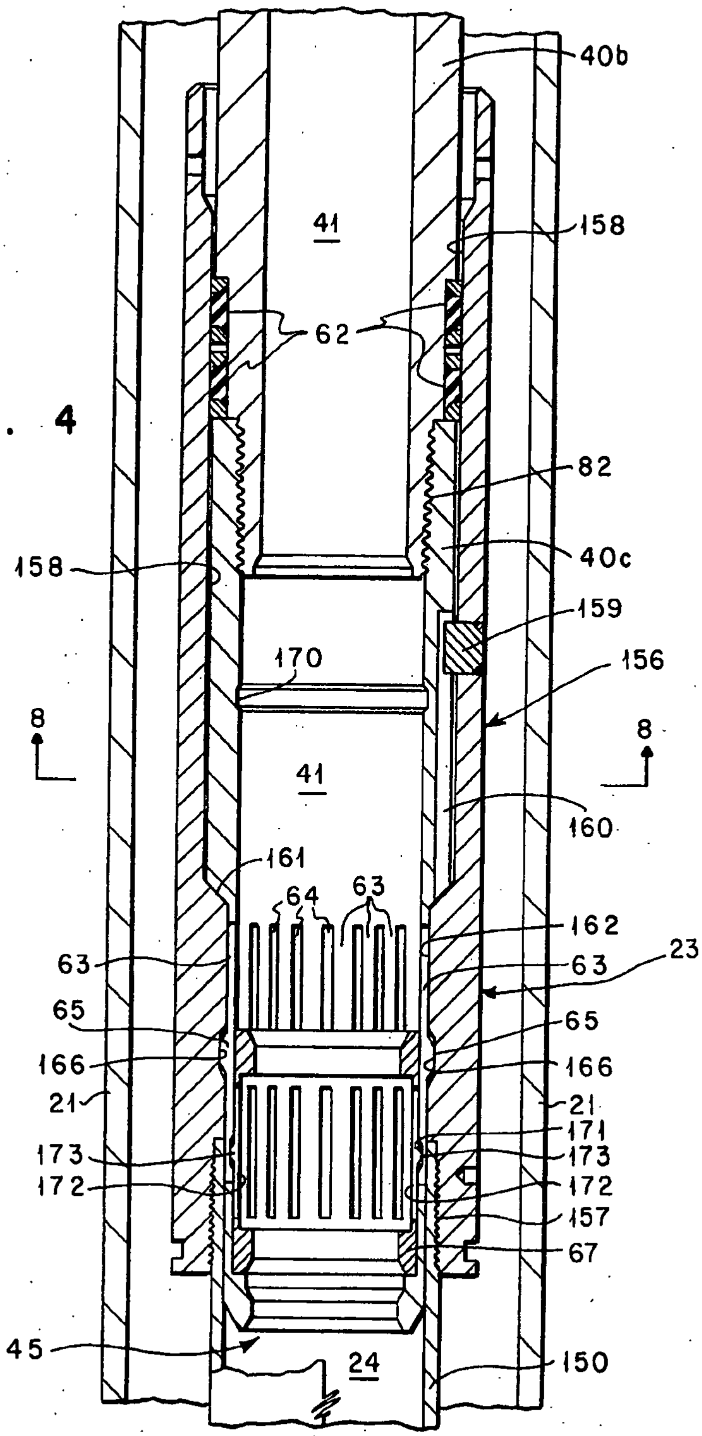
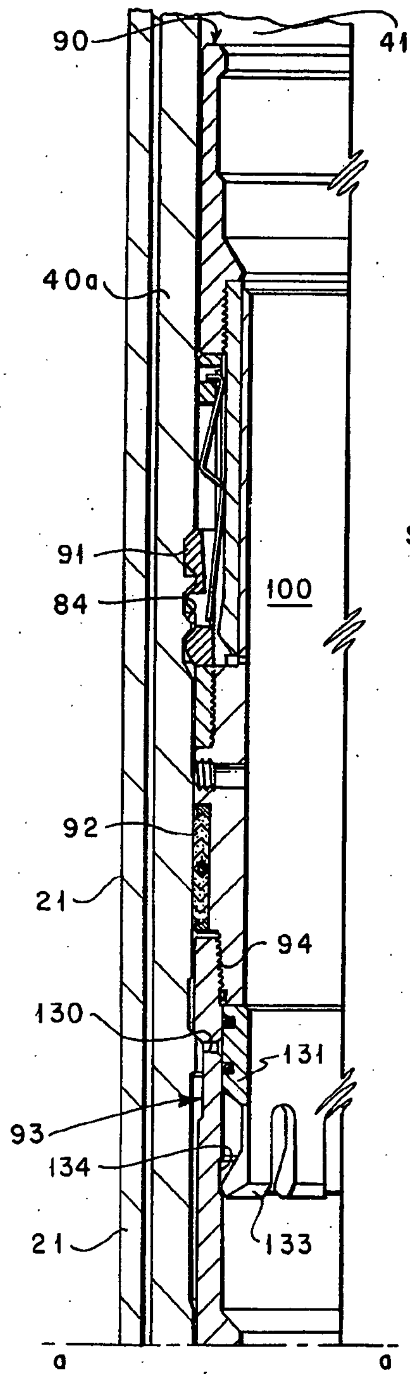
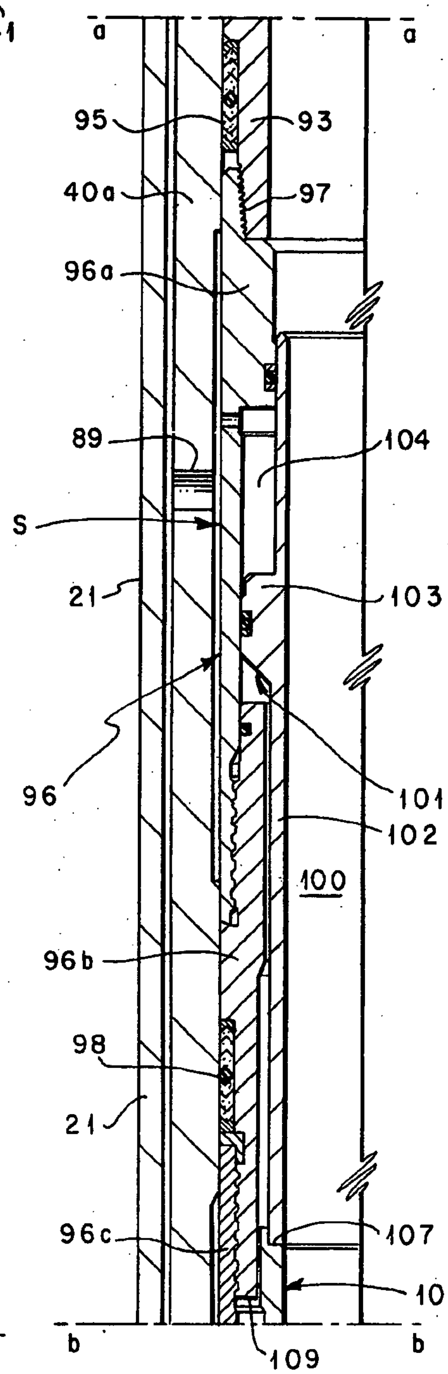

40b
41
158
62
82
158
40c
159
170
156
8
8
41
160
161
64
63
162
63
63
23
65
65
166
166
21
21
171
173
173
172
172
157
67
45
24
150

FIG. 4



90
41
40a
91
84
100
92
21
94
130
131
93
134
21
133
a
a


FIG. 5A



a
a
95
93
40a
97
96a
89
104
S
21
103
96
101
102
100
96b
98
21
96c
107
105
109
b
b


FIG. 5B

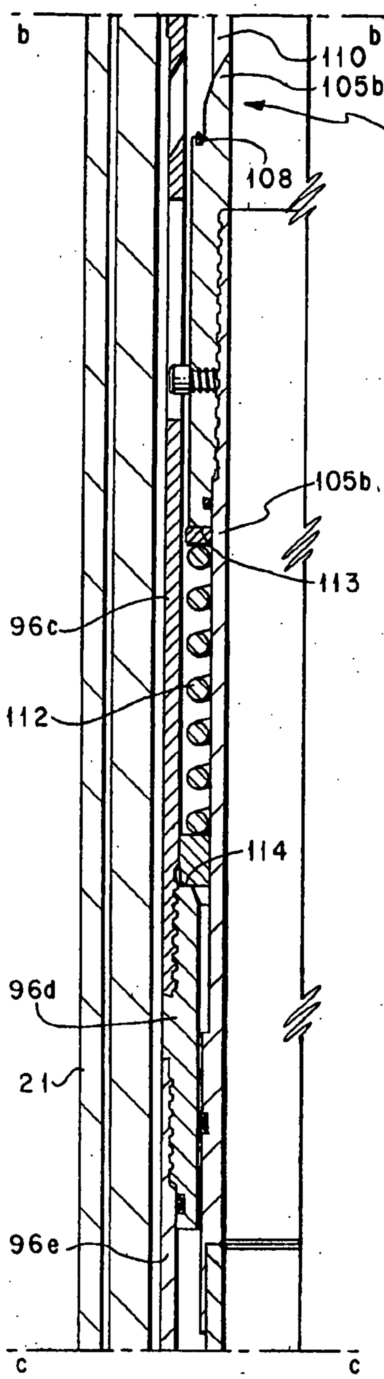

b
b
110
105b
106
108
105b, 117
113
96c
112
114
96d
21
96e
c
c

FIG. 5C

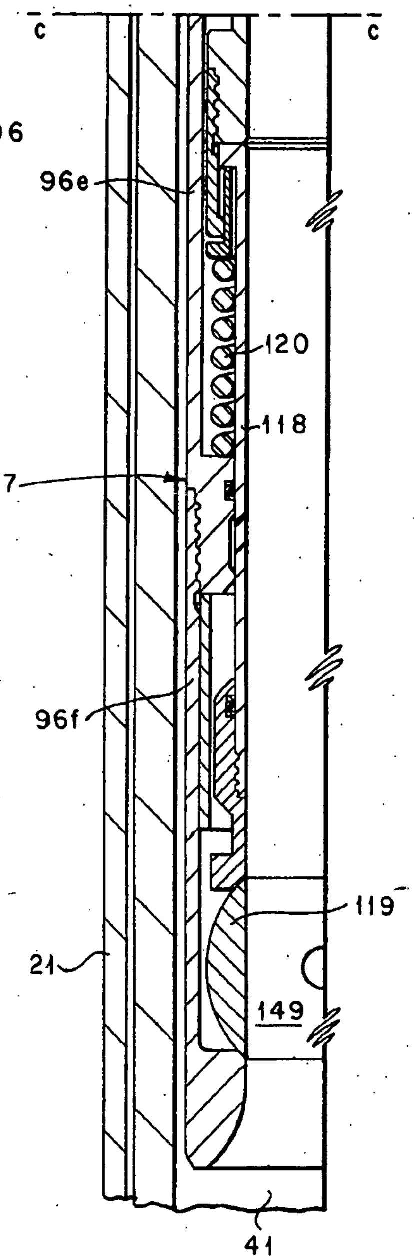

c
c
96e
120
118
96f
119
21
149
41

FIG. 5D

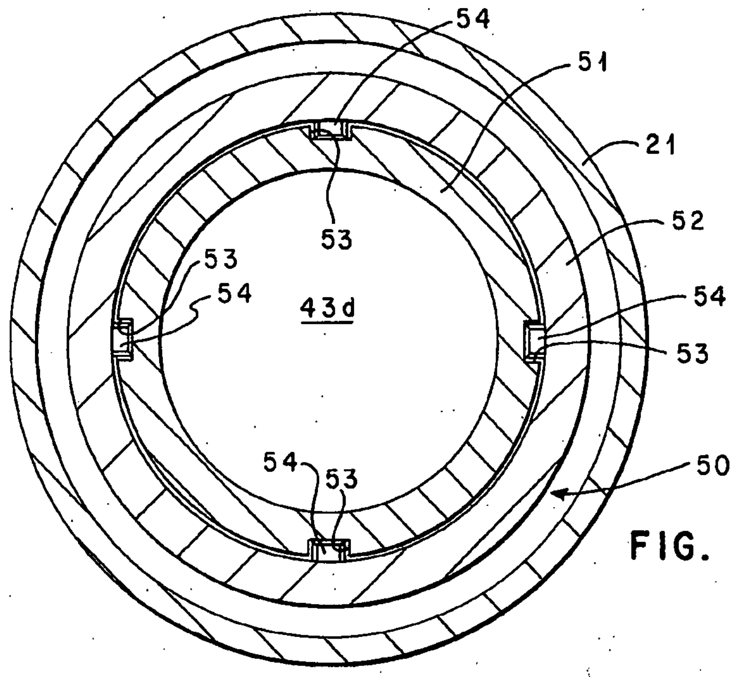

54
51
21
53
52
53
54
43d
54
53
54
53
50

FIG. 6

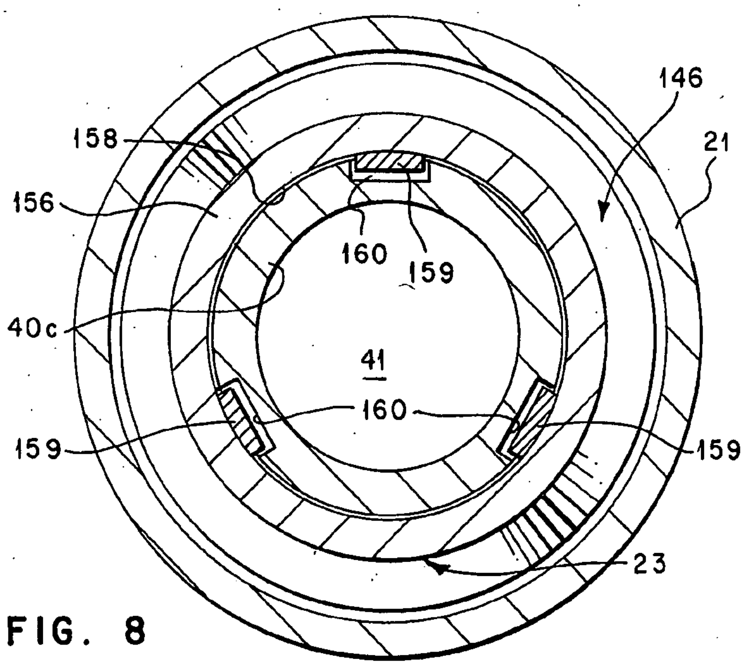

146
21
158
156
160
159
40c
41
160
159
159
23

FIG. 8

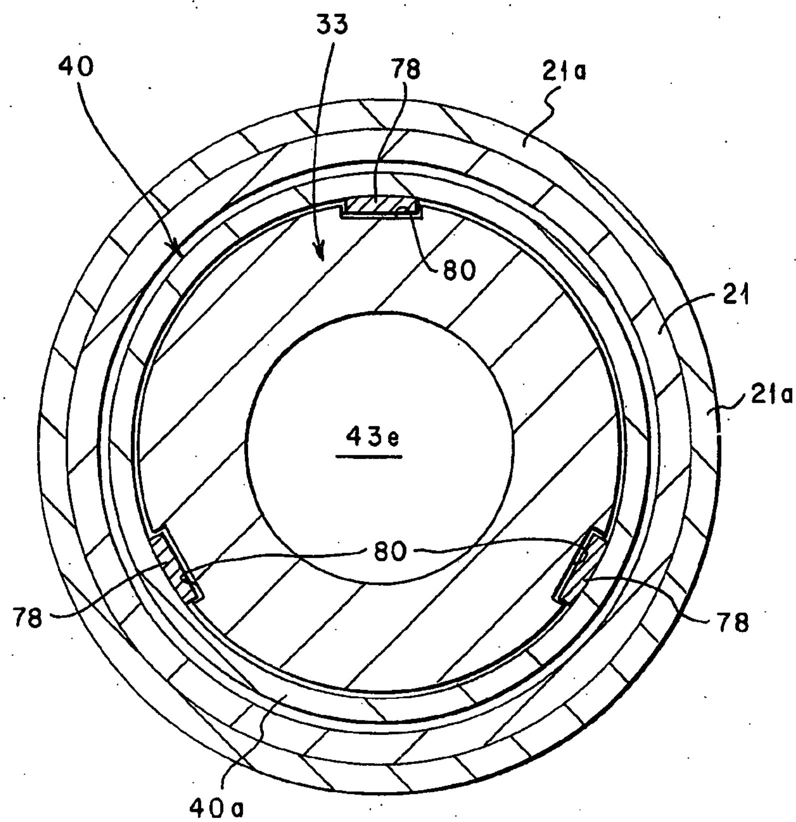



FIG. 7

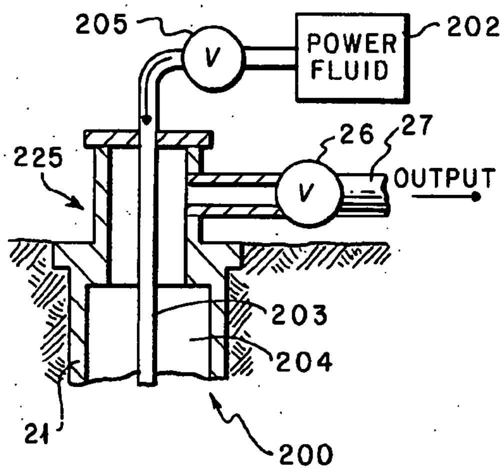



FIG. 9

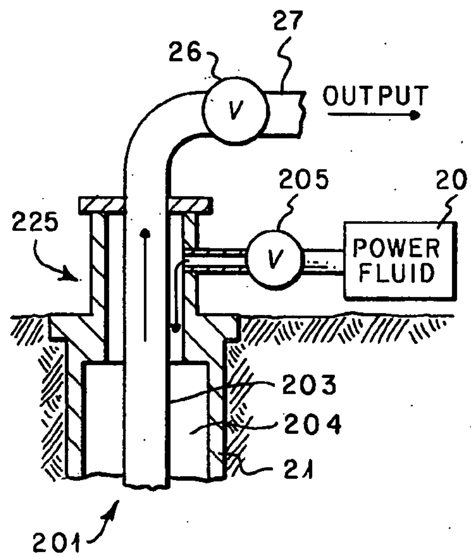



FIG. 11

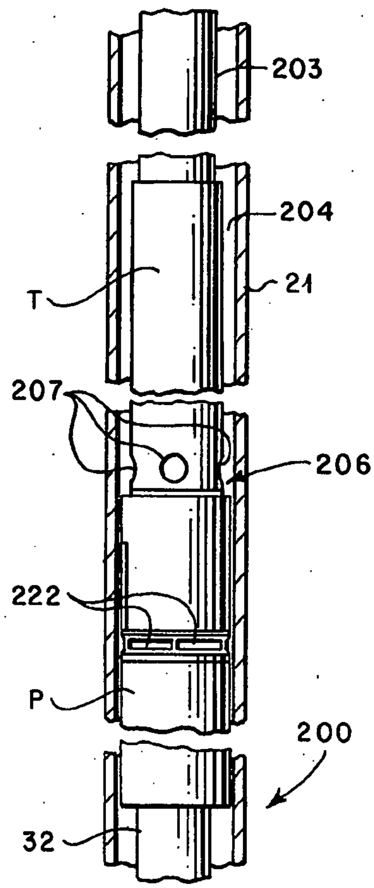



FIG. 10

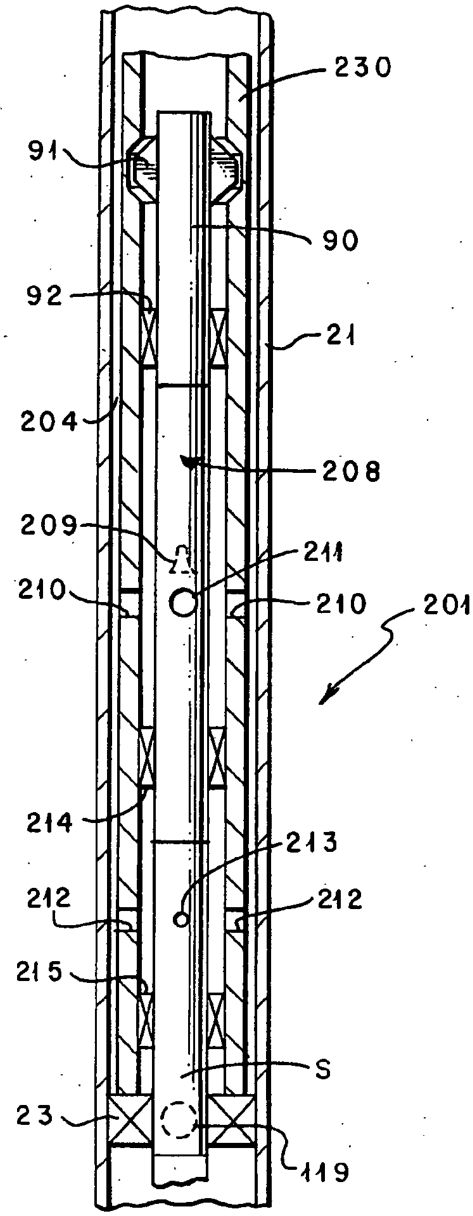

230
91
90
92
21
204
208
209
211
210
210
201
214
213
212
212
215
S
23
119

FIG. 12

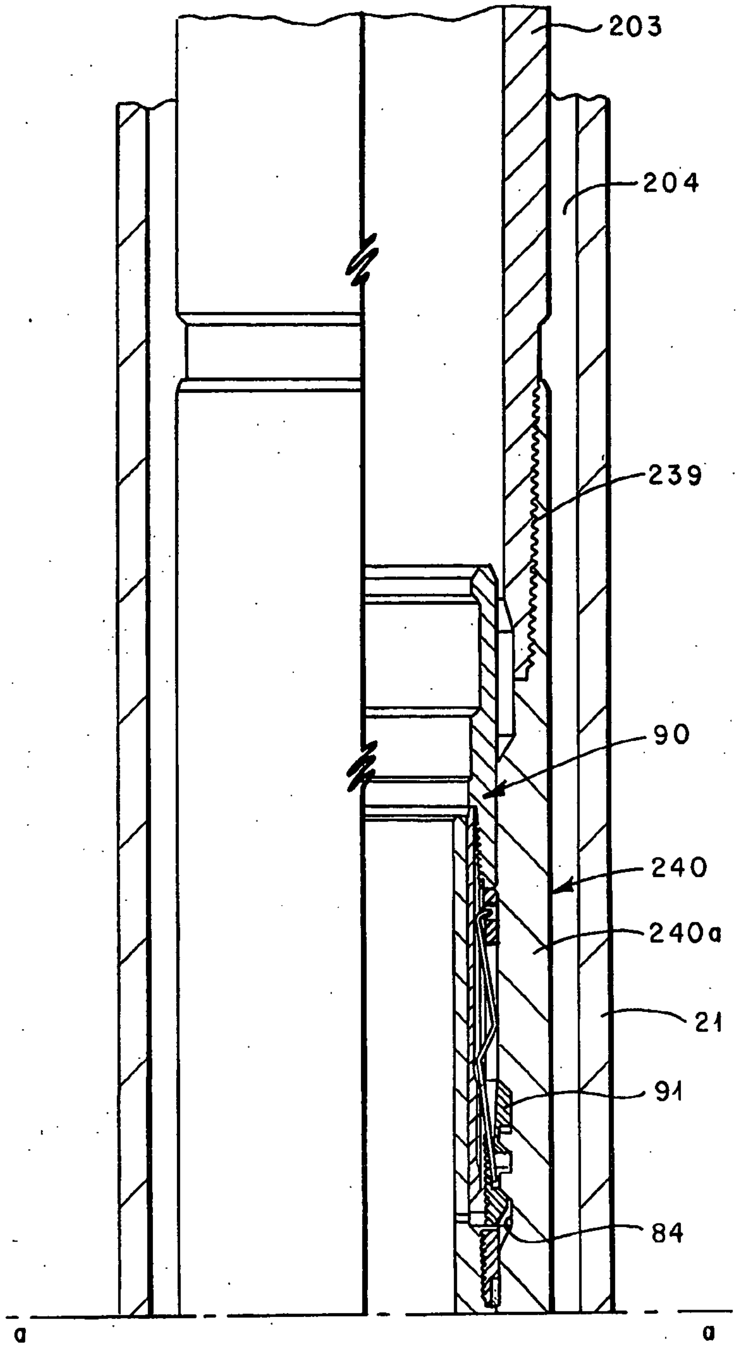



FIG. 13A

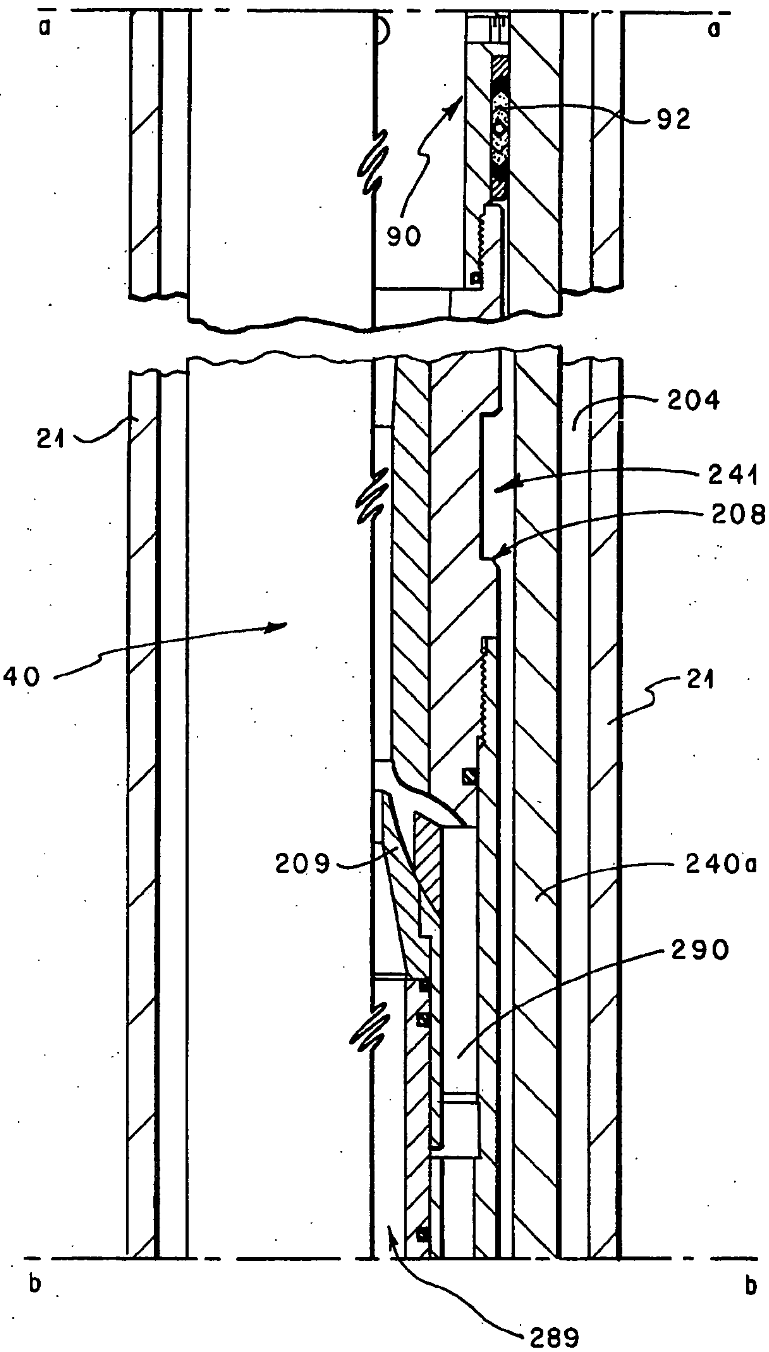



FIG. 13B

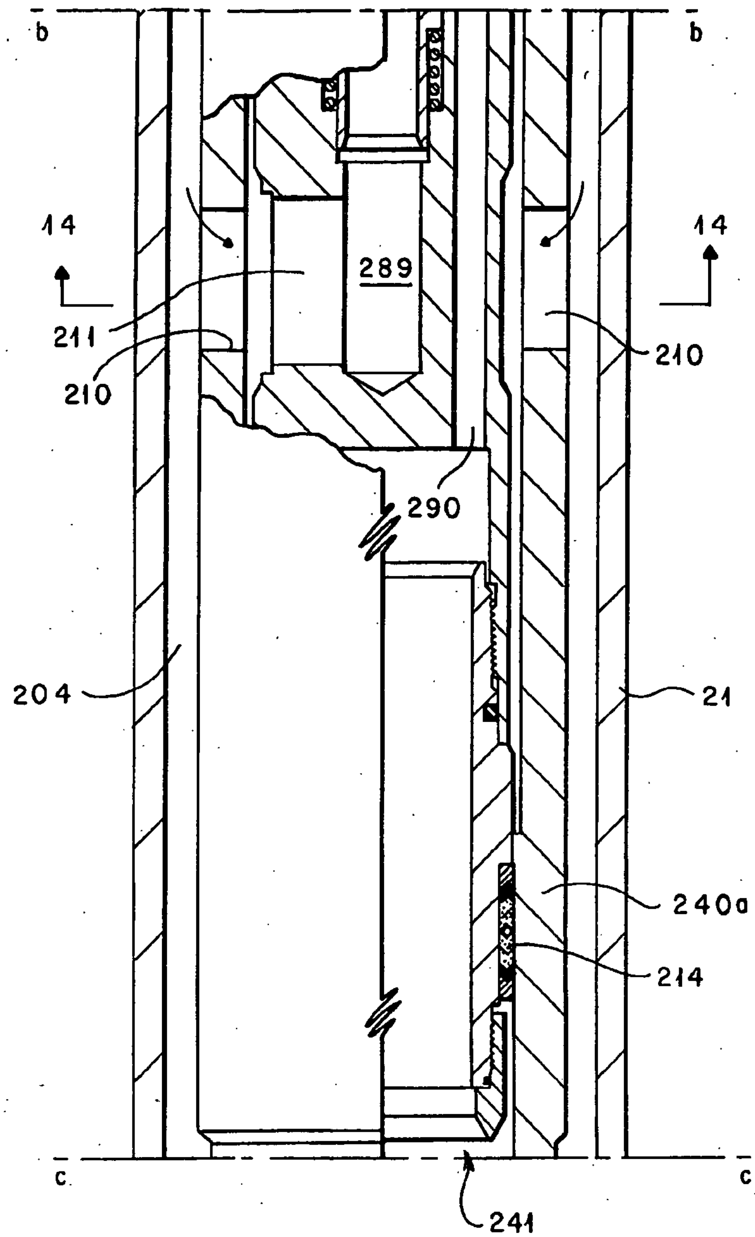



FIG. 13C

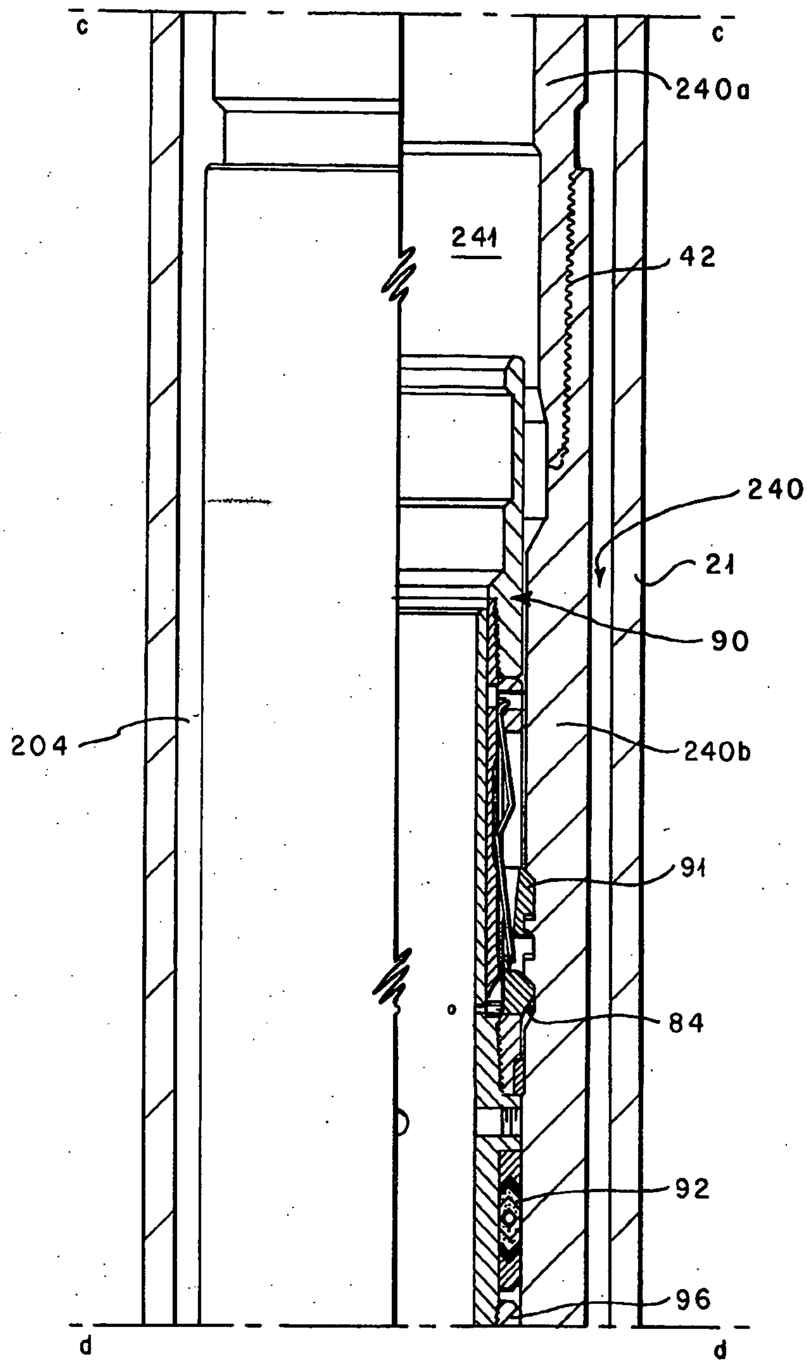



FIG. 13D

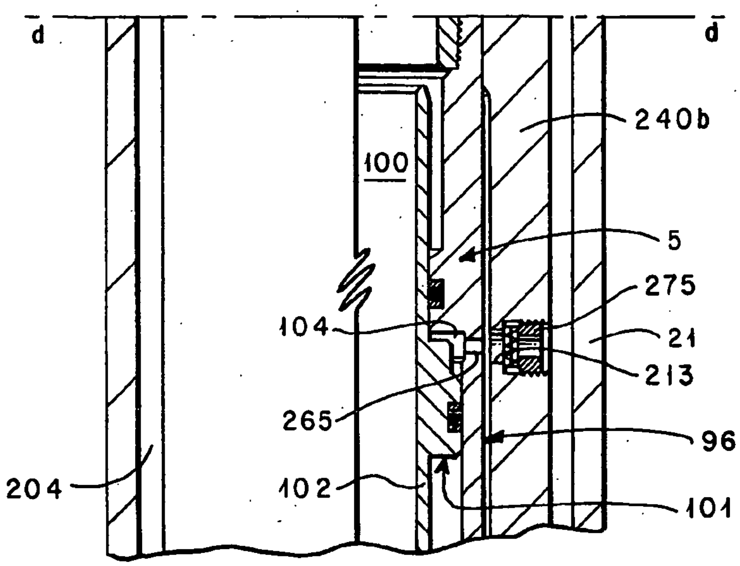



FIG. 13E

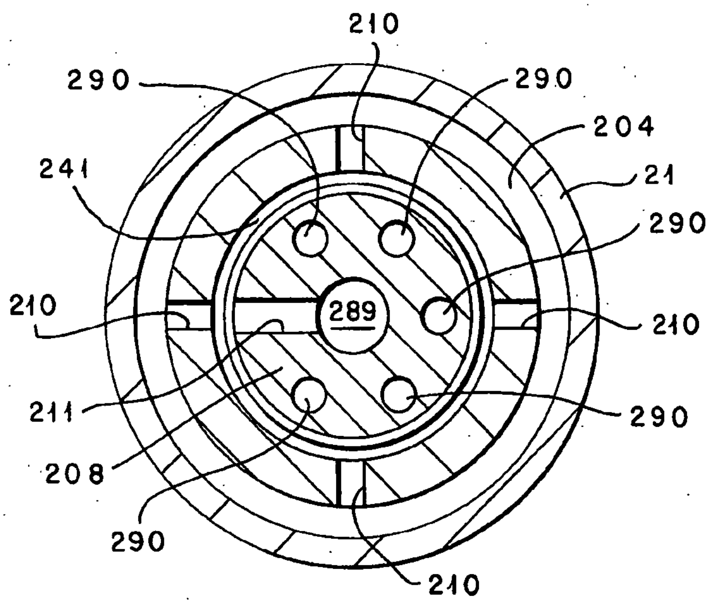



FIG. 14

## SUBMERSIBLE PUMP INSTALLATION, METHODS AND SAFETY SYSTEM

This is a continuation-in-part application of my presently pending U.S. patent application Ser. No. 470,581 filed on Feb. 28, 1983 now U.S. Pat. No. 4,529,035.

### BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to submersible pump installations for wells and to a safety system which maintains the well under control.

2. Description of the Prior Art

In some hydrocarbon producing formations, sufficient reservoir pressure may be present to cause formation fluids to flow to the well surface. However, the hydrocarbon flow resulting from the natural reservoir pressure may be significantly lower than the desired flow. For these types of wells, electrically powered submersible pumps are sometimes installed to achieve the desired hydrocarbon flow rate. Submersible pumps can be used to raise various liquids to the well surface. Examples of prior art submersible pump and safety valve installations are shown in U.S. Pat. Nos. 3,853,430; 4,121,659; 4,128,127; 4,134,454; 4,425,965; and 4,440,221. The present invention is not limited to electrically powered submersible pumps. Examples of downhole jet pumps which can be used with the present invention are disclosed in U.S. Pat. Nos. 4,390,061 and 4,441,861. Other hydraulically powered pumps such as turbine driven pumps may also be used. The preceding patents are incorporated by reference for all purposes within this application.

### SUMMARY OF THE INVENTION

The present invention discloses a well completion having a submersible pump with an intake and a discharge disposed within a well flow conductor comprising packer means for forming a fluid seal with the interior of the flow conductor at a downhole location to direct fluid flow to the pump intake; a landing nipple releasably secured to the upper portion of the packer means; a longitudinal passageway extending through the landing nipple; a safety valve releasably secured within the longitudinal passageway for controlling fluid flow therethrough; means for attaching the submersible pump to the landing nipple above the safety valve; and the longitudinal passageway providing a portion of the means for directing fluid flow to the pump intake.

One object of the invention is to provide a submersible pump installation having a safety system including a subsurface safety valve which is controlled by hydraulic pressure from the pump discharge.

Another object of the invention is to provide a landing nipple for installing a submersible pump and a safety valve at a downhole location. The submersible pump, safety valve, and landing nipple are retrievable from within the flow conductor. The safety valve blocks fluid flow to the well surface when the submersible pump is not operating and when the submersible pump has been retrieved from the landing nipple.

A further object of the invention is to provide a submersible pump installation including a universal landing nipple in which various submersible pumps and safety valves can be mounted.

A still further object of the invention is to provide a landing nipple which can be releasably secured to various well packers.

An additional object of the present invention is to provide a safety system for hydraulically powered submersible pumps. The safety system may be operated by either the discharge pressure from the submersible pump or the input power fluid supplied to the submersible pump.

Additional objects and advantages of the invention will be readily apparent to those skilled in the art from reading the following description in conjunction with the drawings and claims.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B are schematic views partially in longitudinal section and partially in elevation showing a well completion with a submersible pump and safety system of the present invention.

FIGS. 2A-J are drawings partially in section and partially in elevation showing the submersible pump attachments and safety system of FIG. 1 disposed within a casing string. The safety system is shown in its first or closed position blocking fluid flow through the packer mandrel.

FIG. 3 is an enlarged drawing in longitudinal section showing the engagement between the pump seating mandrel and the landing nipple of the present invention.

FIG. 4 is an enlarged drawing in longitudinal section showing the engagement between the landing nipple and the well packer.

FIGS. 5A-D are drawings in longitudinal half-section with portions broken away showing the safety system of FIG. 1 in its second or open position allowing fluid flow through the flow conductor.

FIG. 6 is a drawing in horizontal section taken along line 6—6 of FIG. 2C.

FIG. 7 is a drawing in horizontal section taken along line 7—7 of FIG. 3.

FIG. 8 is a drawing in horizontal section taken along line 8—8 of FIG. 4.

FIG. 9 is a schematic drawing partially in longitudinal section and partially in elevation showing a wellhead configuration for supplying input power fluid to a hydraulically powered submersible pump.

FIG. 10 is a schematic drawing partially in longitudinal section and partially in elevation showing a turbine driven submersible pump located downhole in a well bore.

FIG. 11 is a schematic drawing partially in longitudinal section and partially in elevation showing a wellhead configuration for supplying input power fluid to a hydraulically powered submersible pump.

FIG. 12 is a schematic drawing partially in longitudinal section and partially in elevation showing a downhole well completion having a jet pump and safety system.

FIGS. 13A-E are drawings partially in section and partially in elevation showing the submersible pump and safety system of FIG. 12 in more detail.

FIG. 14 is a drawing in horizontal section taken along line 14—14 of FIG. 13C.

### DESCRIPTION OF THE PREFERRED EMBODIMENTS

A submersible pump installation and safety system incorporating the present invention are schematically illustrated in FIGS. 1A and 1B. Well 20 is partially

defined by casing or flow conductor 21 which extends from wellhead 25 to a producing formation (not shown). Couplings 21a are used to connect the joints of casing 21 with each other. Well packer means 23 with packer bore 24 extending therethrough forms a fluid barrier with the interior of casing 21 to direct fluid flow from the producing formation to the well surface via packer bore 24. Valve 26 controls production fluid flow from wellhead 25 into surface flowline 27.

To increase production fluid flow, submersible pump P is shown suspended within flow conductor 21 by electrical cable C. Pump P is driven by electrical motor 28 to discharge formation fluids from outlets or discharge ports 22 into the bore of casing 21 above packer 23. Accumulator means 30 is attached to and extends downwardly from pump inlet 32. Preferably, travel joint 50 is attached below accumulator means 30. Pump support means or seating mandrel 33 is attached below travel joint 50. The weight of pump P, motor 28, accumulator means 30 and travel joint 50 is supported partially by the contact between seating mandrel 33 and landing nipple 40 and partially by cable C. Cable C also supplies electrical power from the well surface to motor 28. Wellhead 25 includes packing means 34 which forms a fluid barrier around cable C and prevents undesired fluid flow therepast. Pump P, motor 28, and cable C are commercially available from various companies. One such company is REDA Pump Division of TRW in Bartlesville, Okla.

Bore 43 extends longitudinally through pump inlet 32, accumulator means 30, swivel connector means 29, travel joint 50 and pump seating mandrel 33. Bore 43 provides a flow path for formation fluids to enter pump P. Bore 43 is given an alphabetic designation within each component attached to pump P to aid in describing the invention. As shown in FIGS. 2A-2D, appropriately sized o-rings are included within each connection between the various components attached to pump P to prevent undesired fluid communication between bore 43 and the exterior of the components.

Pump inlet 32 is attached by bolted connection 38 to accumulator 30 as shown in FIG. 2A. One advantage of the present invention is that various submersible pumps can be attached to inlet 32 and satisfactorily installed within casing 21. Also, the components of the submersible pump installation could be connected to each other by means other than bolted connections 38. The total length of the submersible pump installation including motor 28, pump P, accumulator means 30, travel joint 50 and seating mandrel 33 requires the use of swivel connector means 29 between various components. Swivel connector means 29 compensate for deviations of casing 21 while raising and lowering pump P and attached components. Swivel connector means 29 may also be classified as a flexible joint or articulated joint. Installing several swivel connector means 29 allows limited flexing of the components relative to each other while installing and retrieving pump P. However, swivel connector means 29 are designed to prevent rotation of the components attached thereto relative to each other. Swivel connector means 29 allows accumulator means 30 and travel joint 50 to flex relative to each other in one plane as determined by keys 48 and keyways 49. In the same manner, a swivel connector means 29 is preferably installed between travel joint 50 and seating mandrel 33 as shown in FIGS. 2C and 2D.

When pump P is turned off, safety valve S will close. Accumulator means 30 communicates with pump inlet 32 to supply a reservoir of fluid to allow discharge pressure from pump P to open safety valve S when pump P is turned on. Swivel connector means 29 allows the attachment of as many accumulator means 30 as required for each submersible pump installation. In FIG. 1A, only one accumulator means 30 is shown, but others may be added as desired.

Travel joint 50 comprises primarily two long, hollow cylinders 51 and 52. Cylinder 51 is sized to telescope within cylinder 52. Keyways 53 are machined longitudinally into the exterior of cylinder 51. Matching keys 54 are carried by cylinder 52 and slide longitudinally in keyways 53. Keys 54 and keyways 53 cooperate to prevent rotation of cylinders 51 and 52 with respect to each other. Packing means 55 is carried on cylinder 51 near its extreme end disposed within cylinder 52. Packing means 55 forms a fluid barrier with the adjacent inside diameter of cylinder 52 as cylinders 51 and 52 telescope longitudinally relative to each other. Travel joint 50 is preferably installed with cylinder 51 telescoped approximately 50% into cylinder 52. This results in cable C carrying the weight of pump P and the components above cylinder 51. This weight maintains cable C taut without overstressing it. The weight of cylinder 52 and the components therebelow is supported by contact between seating mandrel 33 and landing nipple 40. The extreme ends of travel joint 50 have appropriate bolted connections 38 for attachment to adjacent components.

Seating mandrel 33, attached to travel joint 50 by a swivel connector means 29, is a relatively short hollow cylinder with bore 43e extending therethrough. Packing means 79 are carried on the exterior of seating mandrel 33 below keyways 80. Packing means 79 are sized to form a fluid barrier with inside diameter 81 of landing nipple 40. Packing means 79 blocks fluid discharged from pump outlets 22 from flowing downwardly through longitudinal passageway 41 of landing nipple 40. A plurality of keyways 80 extend longitudinally through a portion of the exterior of seating mandrel 33. Matching keys 78 project radially inward from the interior of longitudinal passageway 41 and engage keyways 80. Keys 78 and keyways 80 cooperate to prevent rotation of seating mandrel 33 and landing nipple 40 relative to each other. Various mechanisms other than keys 78 and keyways 80 could be used to secure seating mandrel 33 within landing nipple 40 and prevent rotation of the components relative to each other. U.S. Pat. Nos. 4,363,359 and 4,121,659 disclose such mechanisms.

For ease of manufacture and assembly, landing nipple 40 has an upper section 40a, a middle section 40b and a lower section 40c threadedly engaged to each other. Upper section 40a and middle section 40b comprise tubular housing means with longitudinal passageway 41 extending therethrough. Section 40a is engaged with section 40b by threads 42 as shown in FIG. 2H. Upper section 40a is shown as a relatively long piece to accommodate both pump seating mandrel 33 and safety valve S. If desired, upper section 40a could be manufactured from several shorter hollow tubular sections with appropriate threaded connections to engage the shorter tubular sections with each other. Lower section 40c is an adapter sub engaged to middle section 40b by threads 82 as shown in FIGS. 2H and 4. Longitudinal passageway 41 extends through lower section 40c and communicates with well packer bore 24. A portion of the outside diameter of lower section 40c is sized to be received within upper portion 156 of well packer 23. Collet as-

sembly 45 on lower section 40c provides means for releasably securing landing nipple 40 with well packer 23 to allow fluid communication between longitudinal passageway 41 and packer bore 24.

End 46 of upper section 40a (the other end of landing nipple 40 opposite from collet assembly 45) is sized to receive seating mandrel 33 partially into longitudinal passageway 41. The portion of longitudinal passageway 41 adjacent to the other end 46 has first inside diameter 60 larger than the inside diameter of the remainder of longitudinal passageway 41. Seating shoulder 44 is formed on the interior of longitudinal passageway 41 by the transition between the inside diameters thereof. Keys 78 project radially inward from first inside diameter portion 60. Honed sealing surface 81 is provided on the interior of longitudinal passageway 41 adjacent to seating shoulder 44. When keys 78 are engaged with keyways 80 and pump seating mandrel 33 is resting on seating shoulder 44, packing means 79 forms a fluid barrier with honed surface 81. A set of locking grooves 84 is machined in the interior of longitudinal passageway 41 in nipple section 40a below shoulder 44 to provide part of the means for installing safety valve S within landing nipple 40. U.S. Pat. No. 3,208,531 to J. W. Tamplen discloses a locking mandrel and running tool which can be used to install safety valve S within landing nipple 40.

As best shown in FIG. 2H, middle section 40b is preferably a heavy, thick walled tubular housing means. The extra weight of this section assists in engaging landing nipple 40 with well packer 23. A portion of middle section 40b and all of lower section 40c are sized to fit within the upper portion of packer bore 24. Tapered surface 146 on the exterior of middle section 40b is formed by the major change in outside diameter of middle section 40b.

Packing means 62 are carried on the portion of middle section 40b which fits within packer bore 24. Packing means 62 forms a fluid barrier with the interior of well packer 23 adjacent thereto. Lower section or adapter sub 40c is attached to middle section 40b by threads 82. Collet assembly 45 carried near the extreme end of adapter sub 40c provides means for releasably locking adapter sub 40c to well packer 23.

The releasable locking means includes flexible collet fingers 63 formed in the exterior of adapter sub 40c by longitudinal slots 64 as best shown in FIG. 4. Bosses 65 project radially outward from each collet finger 63 intermediate the ends thereof. Bosses 65 are sized to engage annular groove 166 within packer bore 24. Sleeve 67 is slidably disposed within adapter sub 40c. Sleeve 67 has a first position which prevents fingers 63 from flexing and a second position which allows fingers 63 to flex radially inward to release landing nipple 40 from well packer 23. Sleeve 67 has a plurality of collet fingers 172 formed through its exterior similar to collet fingers 63. Bosses 173 project radially outward from each collet finger 172 intermediate the ends thereof. The first position of sleeve 67 is defined by bosses 173 engaging annular groove 171 formed on the interior of longitudinal passageway 41. The second position of sleeve 67 is defined by bosses 173 engaging annular groove 170 formed on the interior of longitudinal passageway 41. Annular groove 170 is located above collet fingers 63 such that when sleeve 67 is engaged with annular groove 170, collet fingers 63 are free to flex radially inward. Conventional wireline techniques and tools can be used to shift sleeve 67 between its first and second position.

Port means 89 extend radially through upper section 40a intermediate the ends thereof. The longitudinal spacing of port means 89 relative to locking grooves 84 is selected to allow fluid communication between the exterior of landing nipple 40 and safety valve S installed within longitudinal passageway 41. Fluid pressure from pump discharge ports 22 is communicated with port means 89 via the annulus formed by the interior of casing 21 and the exterior of landing nipple 40. Preferably, well packer 23 and the components attached thereto are located within casing 21 such that a liquid level is always maintained above discharge ports 22. This liquid level is required for satisfactory operation of safety valve S.

Locking mandrel 90 carries dogs 91 which coact with grooves 84 to anchor safety valve S within longitudinal passageway 41. Sealing means 92 are carried on the exterior of locking mandrel 90 to form a first fluid barrier with the inside diameter of nipple section 40a when dogs 91 are secured within grooves 84. Equalizing assembly 93 is attached to locking mandrel 90. Sealing means 95 are carried on the exterior of equalizing assembly 93 to form a second fluid barrier with the inside diameter of nipple section 40a. Sealing means 92 and 95 are spaced longitudinally from each other. Valve housing means 96 is engaged by threads 97 to equalizing assembly 93. Sealing means 98 are carried on the exterior of housing means 96 to form a third fluid barrier with the interior of nipple section 40a.

Safety valve S includes locking mandrel 90, equalizing assembly 93, valve housing means 96 and the valve components disposed therein. Bore 100 extends longitudinally through safety valve S. Sealing means 92 and 98 cooperate to direct formation fluid flow through bore 100 and block fluid flow between the exterior of valve S and the interior of nipple 40. When the submersible pump installation is operating normally, formation fluids flow from perforations (not shown) into pump P via packer bore 24, longitudinal passageway 41, bore 100, and bore 43.

Valve housing means 96 consists of several concentric, hollow sleeves which are connected by threads to each other. Each housing means subassembly has an alphabetic designation. Hydraulically actuated means 101 comprising operating sleeve 102 and piston 103 are slidably disposed within bore 100. Increasing fluid pressure in variable volume chamber 104 will cause operating sleeve 102 to slide longitudinally relative to housing means 96. Inner cylinder 105, which has two subsections designated 105a and 105b, of poppet valve means 106 abuts the extreme end of operating sleeve 102 at 107. Elastomeric seal 108 is carried on the exterior of inner cylinder 105 intermediate the ends thereof. Metal seating surface 109 is provided on the interior of housing means 96 facing elastomeric seal 108. A plurality of openings 110 extends radially through inner cylinder section 105a. Another plurality of openings 111 extends radially through housing subassembly 96c. When safety valve S is in its first position as shown in Fig. 2F, elastomeric seal 108 contacts metal seating surface 109 blocking fluid communication through openings 110 and 111. When operating sleeve 102 slides longitudinally in one direction, it will contact inner cylinder 105 and displace elastomeric seal 108 away from metal seating surface 109. This displacement allows fluid communication through openings 110 and 111 as shown in FIG. 5C.

Spring 112 disposed between shoulder 113 on the exterior of inner cylinder section 105*b* and shoulder 114 of housing means 96 urges elastomeric seal 108 to contact metal seating surface 109.,

Poppet valve means 106 is included within safety valve S because openings 110 and 111 have a large flow area as compared to bore 100. Also, poppet valve means 106 is easily pressure balanced so that less control fluid pressure is required to displace elastomeric seal 108 away from metal seating surface 109 as compared to opening a ball type valve.

Ball valve means 117 is disposed within safety valve S below poppet valve means 106. Operating sleeve 118 of ball valve means 117 is spaced longitudinally away from inner cylinder section 105*b* when poppet valve means 106 is closed. When piston 103 shifts poppet valve means 106 to its open position, inner cylinder section 105*b* will contact operating sleeve 118 to rotate ball 119 to align bore 149 of ball 119 with bore 100 as shown in FIG. 5D. Ball valve means 117 is open when bore 149 is aligned with bore 100. Ball valve means 117 is shut when bore 149 is rotated normal to bore 100. Spring 120 urges ball 119 to rotate to block bore 100 when fluid pressure is released from variable volume chamber 104.

Ball valve means 117 is a normally closed safety valve which is opened by inner cylinder section 105*b* of poppet valve means 106 contacting operating sleeve 118. Both poppet valve means 106 and ball valve means 117 operate in substantially the same manner as other surface controlled subsurface safety valves. Control fluid pressure is applied to piston 103 to shift safety valve S to its second or open position. When control fluid pressure is released from variable volume chamber 104, springs 112 and 120 cooperate to return safety valve S to its first or closed position blocking fluid flow through bore 100. As will be explained later, control fluid pressure acting on piston means 103 is supplied from the discharge of pump P.

Since inner cylinder section 105*b* is spaced longitudinally from operating sleeve 118 when safety valve S is in its first position, poppet valve means 106 will open first when pump P is started. Well fluids will initially flow into bore 100 above ball 119 through openings 110 and 111 to equalize any pressure difference across ball 119 and to supply well fluids to pump inlet 32. Thus, accumulator means 30 must contain at least enough fluid to open poppet valve means 106. Also, equalizing the pressure difference across ball 119 prior to rotating ball 119 significantly reduces the force required to open ball valve means 117 and minimizes the possibility of damage to safety valve S. If desired, a flapper valve could be substituted for ball valve means 117. U.S. Pat. No. 4,440,221 to D. F. Taylor et al fully explains the operation of safety valve S.

Equalizing assembly 93 is positioned within safety valve S between locking mandrel 90 and valve housing means 96. Equalizing assembly 93 provides means for selectively equalizing fluid pressure between bore 100 and the exterior of safety valve S while installing and removing safety valve S from longitudinal passageway 41. A plurality of apertures 130 extend radially through equalizing assembly 93. Sliding sleeve 131 with a pair of o-ring seals 132 carried on its exterior is disposed within equalizing assembly 93. O-ring seals 132 are spaced from each other so that when sleeve 131 is in its first or upper position, o-ring seals 132 will straddle apertures 130 blocking fluid flow therethrough. Collet fingers 133 are carried by sleeve 131 to engage groove 134 and hold sleeve 131 in its first position. Various wireline tools are commercially available which can be lowered from the well surface through casing 21, after pump P has been removed, to shift sleeve 131 to either open or block apertures 130.

Longitudinal flow path 86 is provided in the exterior of landing nipple 40 to communicate well fluids from below sealing means 98 to equalizing assembly 93. Radial port 135 extends from longitudinal passageway 41 through nipple 40 to the upper end of longitudinal flow path 86. Radial port 135 is positioned adjacent to apertures 130 between sealing means 92 and 95. Therefore, control fluid or pump discharge fluid is blocked by sealing means 95 from communicating with longitudinal flow path 86. The lower end of longitudinal flow path 86 communicates with longitudinal passageway 41 below packing means 98 through openings 145.

A wide variety of commercially available production well packers can be used with the present invention. The only requirement is that the upper portion of the well packer must be modified to allow releasably securing landing nipple 40 therein. Well packer means 23 as shown in FIGS 1B, 2I and 2J is set by a commercially available electric setting gun and can be retrieved from its downhole location if desired. Packers set by other techniques and permanently set packers may also be used.

The various components which comprise well packer means 23 are carried by and assembled on packer mandrel 150. Packer bore 24 extends longitudinally through packer mandrel 150. Slip elements 151 and 152 are slidably disposed on the exterior of packer mandrel 150 with packing elements 153 therebetween. Well packer means 23 is installed at the desired downhole location within flow conductor 21 by radially expanding slip elements 151 and 152 to cause teeth 154 on the exterior of each slip element to bite into the interior of flow conductor 21 adjacent thereto. Packing means 153 is also compressed and radially expanded to form a fluid barrier between the exterior of packer mandrel 150 and the interior of flow conductor 21. Internal slip segments 155 hold slip elements 151 and 152 and packing means 153 in their radially expanded or set position.

Upper portion 156 of well packer means 23 comprises an extension of packer mandrel 150 with packer bore 24 extending therethrough. Upper portion 156 could be engaged by threads 157 to the packer mandrel of various commercially available production well packers.

Inside diameter 158 of packer bore 24 within upper portion 156 is enlarged to receive the lower end of landing nipple 40 or lower section 40*c* therein. A plurality of keys 159 projects radially inward from inside diameter 158 to engage matching keyways 160 in the exterior of lower section 40*c*. Shoulder 161 is formed on the interior of packer bore 24 by the transition from inside diameter 158 to reduced inside diameter 162 of upper portion 156. Inside diameter 158 preferably has a honed sealing surface adjacent to keys 159 to form a fluid barrier with packing means 62 on the exterior of landing nipple 40. Groove 166 is formed within inside diameter 162 to receive bosses 65 of collet assembly 45 therein.

Torque generated by electrical pump P is transmitted from pump seating mandrel 33 via keys 78 and keyways 80 to landing nipple 40. From landing nipple 40 the torque is transmitted to well packer 23 via keys 159 and keyways 160. The engagement of slip elements 151 and

152 and packing means 153 with flow conductor 21 prevents rotation of well packer 23 relative thereto.

From studying the previous description and related drawings, it is readily apparent that the present invention allows a wide variety of subsurface safety valves to be used with the submersible pump installation. The minimum dimensional requirement for selecting an alternative safety valve is that when the valve is attached to threads 94 of locking mandrel 90, sealing means must be positioned on opposite sides of port means 89 to direct control fluid flow to the safety valve's hydraulically actuated means. The minimum operational requirement for alternative safety valves is that relatively low discharge pressure from pump P must be able to open the safety valve.

## INSTALLATION AND OPERATING SEQUENCE

Safety valve S is releasably installed within landing nipple 40 below submersible pump P. Safety valve S can be opened and closed to control the flow of well fluids from the producing formation to the well surface. Pump P and its associated components are not directly attached to safety valve S. Therefore, pump P can be removed from its downhole location for maintenance and/or repair while safety valve S in cooperation with packer 23 blocks undesired formation fluid flow through flow conductor 21 to the well surface. When the complete system is in operation, formation fluids will flow into casing 21 below packer 23 through perforations (not shown). Packer 23 directs the formation fluid flow via packer bore 24 into the lower end of landing nipple 40. Safety valve S in its second or open position allows the formation fluids to continue flowing upwardly through bore 43 of travel joint 50, accumulator means 30 and inlet 32 into pump P. Formation fluids are then pumped to the well surface from discharge ports 22 via casing 21 above well packer 23.

Well packer 23 is installed within flow conductor or casing 21 at the desired downhole location using conventional well completion techniques. Landing nipple 40 is releasably secured to upper portion 156 of well packer 23 by collet assembly 45. Safety valve S is next lowered through flow conductor 21 with equalizing assembly 93 open until locking mandrel 90 is engaged with locking grooves 84 of landing nipple 40. Equalizing assembly 93 is then shut. Springs 112 and 120 cooperate to hold safety valve S in its first position blocking fluid flow to the well surface. Spring 112 holds poppet valve means 106 shut, and spring 120 holds ball valve means 117 shut. Pump P and the components attached thereto can then be lowered through flow conductor 21 until seating mandrel 33 rests on shoulder 44 of landing nipple 40 above safety valve S.

When pump P is turned on, the liquid contained in accumulator means 30 is discharged from pump P to variable volume chamber 104 via port means 89 to open safety valve S. Poppet valve means 106 will open first to increase the supply of liquids to pump inlet 32. Continued operation of pump P will cause further movement of inner cylinder 105 until ball valve means 117 is opened. At this time, well fluids will flow into bore 100 via ball 119 and openings 110 and 111. From bore 100 well fluids will flow through bore 43 into pump inlet 32 and be discharged from outlets 22 to the well surface. The discharge pressure of pump P is applied to variable volume chamber 104 to hold safety valve S open as long as pump P is operating. When pump P is turned off, springs 112 and 120 cooperate to return safety valve S to its first or closed position. Pump P and the components attached thereto may be safely removed from casing 21 when safety valve S is in its first position.

If necessary for well maintenance or workover, safety valve S and landing nipple 40 can be removed from flow conductor 21 by conventional wireline techniques. Thus, the present invention allows for easy repair or replacement of submersible pump P, components attached thereto and the safety system.

## ALTERNATIVE EMBODIMENTS

FIGS. 9 through 14 disclose alternative embodiments of the present invention for use with hydraulically powered submersible pumps. Similar components which perform the same function as previously described will be given the same number.

In FIG. 9, the surface portion of well 200 is shown with wellhead 225 for use with a downhole submersible pump as shown in FIG. 10. Well 200 is partially defined by casing or first flow conductor 21 which extends from wellhead 225 to a producing formation (not shown). Power fluid from source 202 is directed to the submersible pump by tubing string or second flow conductor 203. Source 202 includes the required pumps, filters, valves and fluid reservoirs. Tubing string 203 and casing 21 are coaxial flow conductors which partially define the input power fluid supply circuit and pump discharge or return fluid circuit. Fluid discharged from the submersible pump is returned to the well surface by annulus 204 partially defined by the interior of casing 21 and the exterior of tubing string 203. One or more valves 205 are provided to control input power fluid flow from source 202 into wellhead 225.

As will be explained later in more detail, fluid discharged from the downhole submersible pump is a mixture of input power fluid and formation fluid. If desired, the type of power fluid may be selected to dilute or improve the flowing viscosity of heavy formation fluids or to add corrosion inhibiting fluids. Valve 26 controls discharge flow from wellhead 225 into surface flowline 27. From a functional standpoint, tubing string 203 directs input energy to a fluid driven submersible pump in the same manner as cable C directs electrical energy to an electrical submersible pump. Tubing string 203 may also be used to install, suspend or remove a submersible pump from a wellbore in the same manner as electrical cable C.

FIG. 10 is a schematic representation of a downhole completion compatible with the wellhead configuration of FIG. 9. Submersible pump 206 is attached to tubing string 203 and disposed within casing 21. Pump 206 has two major subsections, turbine chamber T and pump chamber P. Such turbine driven pumps are available from Weir Pumps Limited, Cathcart Glasgow G44 4EX Scotland. Input power fluid flows from the well surface to turbine chamber T via tubing string 203. Power fluid causes rotation of a turbine (not shown) which operates pump P in the same manner as electrical motor 28. Formation fluid enters pump P via inlet 32 and is discharged into annulus 204 via outlets or discharge ports 222. Power fluid exits turbine chamber T via exhaust ports 207 and mixes with formation fluid discharged from pump chamber P in annulus 204. Well packer means 23 (not shown in FIG. 11) can be used to form a fluid barrier with the interior of casing 21 to direct the combined mixture of exhaust fluid and formation fluid to flow to the well surface via annulus 204. Well 200 below pump inlet 32 may be completed in the

same manner as well 20 of FIGS. 1A and B. Safety valve S and associated components may be used with either electrically or hydraulically powered pumps.

In FIG. 11, the configuration of wellhead 225 has been modified to direct input power fluid flow via annulus 204 to a submersible pump such as shown in FIG. 12. Fluid discharged from the submersible pump is directed to the well surface via tubing string 203. Reversing the direction of fluid flow is the principal difference between well 200 of FIG. 9 and well 201 of FIG. 10.

FIG. 12 is a schematic representation of a downhole completion compatible with the wellhead configuration of FIG. 11. Submersible pump 208 is releasably anchored within landing nipple 230 by locking mandrel 90. Landing nipple 230 is similar to previously described landing nipple 40. Landing nipple 230 forms an integral part of tubing string 230 and may be releasably secured to well packer 23 in the same manner as landing nipple 40. Input power fluid flows from annulus 204 into pump 208 via ports 210 and pump power inlet opening 211. Pump 208 includes nozzle 209 which receives input power fluid creating a venturi effect to lift formation fluids to the well surface. Pump 208 is sometimes referred to as a jet pump because of nozzle 209. The operation of pump 208 will be described later in detail.

Input power fluid pressure within annulus 204 also acts upon safety valve S via ports 212 and piston inlet 213. Fluid seal means 214 and 215 are positioned between the exterior of pump 208 and safey valve S to direct input power fluid flow as desired.

FIGS. 13A through 13E provide a more detailed representation of a jet pump and safety valve installation similar to FIG. 12. The principal difference is that FIG. 12 teaches the use of only one locking mandrel 90 with pump P and safety valve S attached thereto. FIGS. 13A through 13E teach using a first locking mandrel 90 for pump 208 and a second locking mandrel 90 for safety valve S. Equalizing assemblies 93 may be installed between locking mandrels 90 and their respective pump 208 and safety valve S.

In FIG. 13A, landing nipple 240 is attached to tubing string 203 by threads 239. Landing nipple 240 with longitudinal passageway 241 extending therethrough is similar to previously described landing nipple 40 and 230. The principal difference is two sets of locking grooves 84 machined in the interior of longitudinal passageway 241. Two port means 210 and 212 extend radially through landing nipple 240 in the same manner as landing nipple 230. Jet pump 208 is releasably secured to the upper set of locking grooves 84 by its respective locking mandrel 90. Safety valve S is releasably secured to the lower set of locking grooves 84 by its respective locking mandrel 90. Landing nipple 240 can be releasably secured to a well packer in the same manner as described for landing nipple 40.

The longitudinal spacing of packing means 92 and 214 is selected to straddle port means 210 on the interior of longitudinal passageway 241. Packing means 92 and 214 cooperate to direct input power fluid flow from annulus 204 to nozzle 209 via port means 210 and pump power inlet opening 211 and longitudinal passage 289. As best shown in FIG. 14, passage 289 is surrounded by a plurality of longitudinal passageways 290 which allow formation fluid to flow from below pump 208 to the discharge end of nozzle 209. The operation of downhole jet pumps is more fully described in U.S. Pat. Nos. 4,441,861 and 4,390,061. Pump power inlet opening 211, longitudinal passage 289, and longitudinal passageways 290 function as a crossover means to direct power fluid from the exterior of landing nipple 240 to jet pump 208 installed therein. A similar crossover means would also be required if a turbine driven pump was installed within landing nipple 240.

If desired for ease of manufacture and assembly, landing nipple 241 can be manufactured from multiple subsections or subassemblies such as 240*a* and 240*b* as shown in FIG. 13D. The longitudinal spacing of the second set of locking grooves 84 is selected relative to port means 213 to communicate input power fluid from annulus 204 to safety valve S. Opening 265 extends radially through valve housing 96 to communicate this fluid with piston chamber 104. Preferably, filter screen means 275 is inserted into port means 213 to block any particulate contamination in the power input fluid from entering chamber 104.

The submersible pump and safety system of FIGS. 13A–E can be satisfactorily operated by applying sufficient fluid pressure to chamber 104 via annulus 204 to open safety valve S and adjusting the input power fluid flow rate to obtain the desired discharge fluid flow at the well surface. Ball 119 could be replaced by a flapper type valve if desired.

Those skilled in the art will readily see that other hydraulically powered pumps could be used in place of turbine driven pump 206 or jet pump 208.

The previous description and drawings illustrate only one embodiment of the present invention. Alternative embodiments will be readily apparent to those skilled in the art without departing from the scope of the invention which is defined by the claims.

What is claimed is:

1. A well completion having a hydraulically powered submersible pump with an intake and a discharge disposed within a first well flow conductor, comprising:
   a. well packer means for forming a fluid seal with the interior of the first well flow conductor at a downhole location to direct formation fluid flow to the pump intake;
   b. a landing nipple releasably secured to the upper portion of the well packer means;
   c. a longitudinal passageway extending through the landing nipple;
   d. a safety valve releasably secured within the longitudinal passageway for controlling fluid flow therethrough;
   e. means for attaching the submersible pump to the landing nipple above the safety valve;
   f. the longitudinal passageway providing a portion of the means for directing formation fluid flow to the pump intake;
   g. the landing nipple further comprising a tubular housing means with the longitudinal passageway extending therethrough;
   h. locking grooves formed on the interior of the longitudinal passageway intermediate the ends thereof;
   i. the locking grooves providing means for releasably securing the safety valve within the longitudinal passageway;
   j. a second flow conductor extending from the well surface and coaxially disposed within the first flow conductor to form an annulus therebetween; and
   k. the second flow conductor and the annulus cooperating to provide separate flow paths for supplying input power fluid to the submersible pump and for

returning fluid discharged from the pump to the well surface.

2. A well completion as defined in claim 1 further comprising:

a. the safety valve having a first position blocking fluid flow through the longitudinal passageway and a second position allowing fluid flow therethrough;
b. hydraulically actuated means for shifting the safety valve from its first to its second position;
c. means for communicating pump discharge pressure to the hydraulically actuated means; and
d. the safety valve and well packer means cooperating to block fluid flow to the well surface through the flow conductor when the safety valve is in its first position.

3. A well completion as defined in claim 2 wherein the means for communicating pump discharge pressure to the hydraulically actuated means comprises:

a. the well packer means providing a barrier between fluid entering the pump intake and fluid exiting the pump discharge;
b. port means extending radially through the landing nipple allowing fluid communication between the exterior and interior of the landing nipple; and
c. a plurality of sealing means carried on the exterior of the safety valve and positioned to straddle the port means when the safety valve is installed within the longitudinal passageway.

4. A well completion as defined in claim 1 further comprising:

a. the safety valve having a first position blocking fluid flow through the longitudinal passageway and a second position allowing fluid flow therethrough;
b. hydraulically actuated means for shifting the safety valve from its first to its second position;
c. means for communicating input power fluid pressure to the hydraulically actuated means; and
d. the safety valve and well packer means cooperating to block fluid flow to the well surface through the flow conductor when the safety valve is in its first position.

5. A well completion as defined in claim 4 wherein the means for communicating input power fluid pressure to the hydraulically actuated means comprises:

a. port means extending radially through the landing nipple allowing fluid communication between the exterior and interior of the landing nipple; and
b. a plurality of sealing means carried on the exterior of the safety valve and positioned to straddle the port means when the safety valve is installed within the longitudinal passageway.

6. A landing nipple for releasably installing a submersible pump and a safety valve at a downhole location within a well flow conductor, comprising:

a. a tubular housing means with a longitudinal passageway extending therethrough;
b. means for releasably securing one end of the tubular housing means to the upper portion of a well packer to allow fluid communication through the well packer to the longitudinal passageway;
c. locking grooves formed on the interior of the longitudinal passageway intermediate the ends thereof;
d. the locking grooves providing means for releasably securing the submersible pump and the safety valve within the longitudinal passageway;
e. port means extending radially through the landing nipple intermediate the ends thereof; and
f. the port means located to allow fluid communication between the exterior of the landing nipple and both the submersible pump and the safety valve installed within the longitudinal passageway.

7. A landing nipple as defined in claim 6 further comprising:

a. two sets of locking grooves spaced longitudinally from each other within the longitudinal passageway for releasably securing the submersible pump and safety valve respectively within the longitudinal passageway; and
b. separate port means for communicating input fluid pressure with the submersible pump and the safety valve respectively.

* * * * *